

fuel can be supplied uniformly into the combustion chamber 1. It is to be noted that in the combustion chamber 1 a burner may be employed as the combustion means 9.

The reforming reaction unit 2 comprises a coiled pipe filled with a reforming catalyst and has an upper end portion led outwardly from the upper portion of the combustion chamber 1 and fluid-connected with a raw material supply path 6. This raw material supply path 6 includes a raw material pipe 6a for the supply of only a reforming raw material therethrough and a steam pipe 6b for the supply of a steam (water) therethrough, both of said pipes 6a and 6b being joined together on their length. The steam pipe 6b has a portion disposed having been coiled around and in contact with the outer periphery of the combustion chamber 1 so that it can be preheated by heat evolved from the combustion chamber 1. The reforming reaction unit 2 has a lower end portion fluid-connected with an upper end portion of the shift reaction unit 3 through a connection tube that is led outwardly from the upper portion of the combustion chamber 1 after having extended through a center region of the combustion chamber 1.

The shift reaction unit 3 is in the form of a coiled pipe filled with a shift catalyst therein and is introduced within the first duct 43 so as to extend from top to bottom while being wound spirally in the first duct 43.

The CO oxidizing unit 4 is in the form of a coiled pipe filled with a CO oxidizing catalyst therein and is introduced within the second duct 44 so as to extend from bottom to top while being wound spirally in the second duct 44. The CO oxidizing unit 4 has a lower end portion fluid-connected with a lower end portion of the shift reaction unit 3 through a connection tube. This connection tube is provided with an air supply passage 5 for the introduction of air necessitated by and in the CO oxidizing unit 4. The CO oxidizing unit 4 has an upper end portion fluid-connected with a reformed gas discharge passage 7 for drawing the reformed gas outwardly therethrough.

The second duct 44 has a lower end portion provided with an air supply passage 45 through which an external air is introduced into it.

In this reforming apparatus, when the lid 42 is closed to close the main discharge port 41 as shown in FIG. 27(A) and combustion takes place within the combustion chamber 1, the combustion exhaust gas from the combustion chamber 1 flows downwardly through the first duct 43 and subsequently flows upwardly through the second duct 4 before it is discharged to the outside. At this time, the reforming reaction unit 2 is exposed to and heated by the combustion gas of an elevated temperature within the combustion chamber 1, and the shift reaction unit 3 within the first duct 43 and the CO oxidizing unit 4 within the second duct 44 are heated by the combustion exhaust gas emerging outwardly from the combustion chamber. In this way, each of the reaction units is preheated.

On the other hand, when the lid 42 is removed to open the exhaust port 41 as shown in FIG. 27(B), the combustion exhaust gas from the combustion chamber 1 is discharged mainly from the main discharge port 41 and flows little through any one of the first and second ducts 43 and 44. At this time, the shift reaction unit 3 is heated by the radiation and heat transmission in solid from the combustion chamber 1 and also by the heat evolved in the reforming gas flowing therethrough. Accordingly, the shift reaction unit 3 can have its temperature controlled to a lower value than that of the reforming reaction unit 2. On the other hand, the CO oxidizing unit 4 is heated by the radiation and heat transmission in solid from the shift reaction unit 3 and the first

duct 43 and also by the heat evolved in the reforming gas flowing therethrough. This CO oxidizing unit 4 has a temperature controlled to a value lower than that of the shift reaction unit 3 since it is not heated by the combustion exhaust gas and, also, the radiation and the heat transmission in solid have been weakened as compared with those in the shift reaction unit 3. Where the temperature of the CO oxidizing unit 4 is desired to be controlled to a further lower value, the external air has to be introduced from the air supply passage 45 into the second duct 44.

As described above, with the reforming apparatus, at the time of initial run of the apparatus before an actual production of the reformed gas, both of the reforming reaction unit 2 and the shift reaction unit 3 and the CO oxidizing unit 4 can be preheated by effecting combustion within the combustion chamber 1 while the first lid 41 has been closed, whereas during routine run of the apparatus, the first lid 41 opened to allow the temperature of each of the units to be controlled optimally.

INDUSTRIAL APPLICABILITY

The reforming apparatus according to the present invention is useful in providing a reformed gas for use as an electricity generating fuel in, for example, fuel cells. That is, with the reforming apparatus, since the temperature of and in each of the reaction units can be controlled optimally, the high-quality reformed gas with the CO concentration reduced sufficiently can be manufactured. In particular, since each of the reaction units is integrally incorporated, it is easy to design compact and is effective to downsize the fuel cell system.

What is claimed is:

1. A reforming apparatus comprising an integrated structure of three separate units, comprising:

- a raw material reforming unit for steam-reforming a raw material to be reformed and producing a reformed gas containing hydrogen as a principal component, including a heat source that generates heat by combustion of a fuel gas, operable to directly obtain heat for the steam reformation reaction from said heat source;
- a shift reaction unit for decreasing, by water-gas-shift reaction, CO contained in the reformed gas produced in said raw material reforming unit; and
- a CO oxidation unit for further decreasing, by oxidation, CO contained in reformed gas treated in said shift reaction unit;

said raw material reforming unit and said shift reaction unit contain different catalysts, and said shift reaction unit and said CO oxidation unit being arranged in a manner that said shift reaction unit and said CO oxidation unit can be indirectly heated by heat transfer from the heat source of said raw material reforming unit, and further said CO oxidation unit including an outside surface, and being arranged to obtain atmospheric cooling of the outside surface; and

said raw material reforming unit, said shift reaction unit and said CO oxidization unit are concentrically arranged relative to each other with said CO oxidization unit placed on an outer peripheral side of the reforming apparatus.

2. The reforming apparatus according to claim 1, wherein said raw material reforming unit comprises a generally cylindrical combustion chamber as the heat source and a reforming reaction unit for steam-reforming the raw material to produce the reformed gas containing hydrogen as a principal component, said reforming reaction unit, said shift

reaction unit and said CO oxidation unit are concentrically arranged relative to said combustion chamber.

3. The reforming apparatus according to claim 2, wherein said reforming reaction unit is concentrically accommodated within said combustion chamber.

4. The reforming apparatus according to claim 2, wherein said reforming reaction unit is positioned outside said combustion chamber in contact therewith.

5. The reforming apparatus according to claim 2, said combustion chamber comprising a center, and further comprising an incombustible core arranged at the center of said combustion chamber.

6. The reforming apparatus according to claim 2, wherein both of said shift reaction unit and said CO oxidation unit are positioned outside said reforming reaction unit.

7. The reforming apparatus according to claim 6, further comprising a partition wall having a function of regulating heat transfer, the partition wall being interposed between said reforming reaction unit and both of said shift reaction unit and said CO oxidation unit.

8. The reforming apparatus according to claim 6, wherein said reforming reaction unit and said shift reaction unit are connected by a flow path detouring outside both of said shift reaction unit and said CO oxidation unit.

9. The reforming apparatus according to claim 6, wherein said shift reaction unit is arranged on a side adjacent to a high temperature zone of said reforming unit and said CO oxidation unit is arranged on a side adjacent a low temperature said of said reforming reaction unit, so as to be in conformity to a temperature distribution within said reforming reaction unit.

10. The reforming apparatus according to claim 1, wherein each of said shift reaction unit and said CO oxidation unit is arranged in a position which is heated by a burned exhaust gas from said heat source of said raw material reforming unit.

11. A reforming apparatus comprising an integrated structure of three separate units, comprising:

a raw material reforming unit for steam-reforming a raw material to be reformed and producing a reformed gas containing hydrogen as a principal component, including a heat source that generates heat by combustion of a fuel gas, operable to directly obtain heat for the steam reformation reaction from said heat source;

a shift reaction unit for decreasing, by water-gas-shift reaction, CO contained in the reformed gas produced in said raw material reforming unit; and

a CO oxidation unit for further decreasing, by oxidation, CO contained in reformed gas treated in said shift reaction unit;

said raw material reforming unit and said shift reaction unit contain different catalysts, and said shift reaction unit and said CO oxidation unit being arranged in a manner that said shift reaction unit and said CO oxidation unit can be indirectly heated by heat transfer from the heat source of said raw material reforming unit, and further said CO oxidation unit being arranged in a position outside said raw material reforming unit;

said raw material reforming unit comprising a generally cylindrical combustion chamber as the heat source and a reforming reaction unit for steam-reforming the raw material to produce the reformed gas containing hydrogen as a principal component, said reforming reaction unit, said shift reaction unit and said CO oxidation unit are concentrically arranged relative to said combustion chamber; and

further comprising an exhaust chamber, in which a burned exhaust gas from said combustion chamber directly flows, wherein said exhaust chamber is positioned adjacent to and coaxially above said combustion chamber, said shift reaction unit being positioned outside said exhaust chamber, said CO oxidation unit being positioned outside said shift reaction unit.

12. The reforming apparatus according to claim 11, further comprising an air intake for introducing fresh air in between said combustion chamber and said exhaust chamber.

13. The reforming apparatus according to claim 11, further comprising a secondary heating element for heating said exhaust chamber.

14. The reforming apparatus according to claim 11, further comprising an exhaust vent for discharging the burned exhaust gas in said exhaust chamber to the outside, a shutter for selectively opening and closing said exhaust vent, a first duct which is separated from said exhaust chamber and interposed between said shift reaction unit and said CO oxidation unit, and a second duct which is fluid-connected with said first duct and positioned outside said CO oxidation unit.

15. The reforming apparatus according to claim 14, further comprising an air intake for introducing fresh air into said first duct.

16. The reforming apparatus according to claim 12, further comprising an incombustible core arranged at the center of said exhaust chamber.

17. A reforming apparatus comprising an integrated structure of three separate units, comprising:

a raw material reforming unit for steam-reforming a raw material to be reformed and producing a reformed gas containing hydrogen as a principal component, including a heat source that generates heat by combustion of a fuel gas, operable to directly obtain heat for the steam reformation reaction from said heat source;

a shift reaction unit for decreasing, by water-gas-shift reaction, CO contained in the reformed gas produced in said raw material reforming unit; and

a CO oxidation unit for further decreasing, by oxidation, CO contained in reformed gas treated in said shift reaction unit;

said raw material reforming unit and said shift reaction unit contain different catalysts, and said shift reaction unit and said CO oxidation unit being arranged in a manner that said shift reaction unit and said CO oxidation unit can be indirectly heated by heat transfer from the heat source of said raw material reforming unit, and further said CO oxidation unit being arranged in a position outside said raw material reforming unit;

said raw material reforming unit comprising a generally cylindrical combustion chamber as the heat source and a reforming reaction unit for steam-reforming the raw material to produce the reformed gas containing hydrogen as a principal component, said reforming reaction unit, said shift reaction unit and said CO oxidation unit are concentrically arranged relative to said combustion chamber; and

at least one of said reforming reaction unit, said shift reaction unit and said CO oxidation unit is provided on a surface thereof with a heat transfer material having a higher heat conductivity than that of a material of which said surface is composed.

18. The reforming apparatus according to claim 2, wherein said CO oxidation unit includes fins for heat dissipation on an outer surface thereof.

19. A reforming apparatus comprising an integrated structure of three separate units, comprising:

a raw material reforming unit for steam-reforming a raw material to be reformed and producing a reformed gas containing hydrogen as a principal component, including a heat source that generates heat by combustion of a fuel gas, operable to directly obtain heat for the steam reformation reaction from said heat source;

a shift reaction unit for decreasing, by water-gas-shift reaction, CO contained in the reformed gas produced in said raw material reforming unit; and

a CO oxidation unit for further decreasing, by oxidation, CO contained in reformed gas treated in said shift reaction unit;

said raw material reforming unit and said shift reaction unit contain different catalysts, and said shift reaction unit and said CO oxidation unit being arranged in a manner that said shift reaction unit and said CO oxidation unit can be indirectly heated by heat transfer from the heat source of said raw material reforming unit, and further said CO oxidation unit being arranged in a position outside said raw material unit;

said raw material reforming unit comprising a generally cylindrical combustion chamber as the heat source and a reforming reaction unit for steam-reforming the raw material to produce the reformed gas containing hydrogen as a principal component, said reforming reaction unit, said shift reaction unit and said CO oxidation unit are concentrically arranged relative to said combustion chamber; and

further comprising a main exhaust chamber in which a burned exhaust gas from said combustion chamber directly flows, a main exhaust vent for directly discharging the burned exhaust gas in said main exhaust chamber to the outside, a shutter for selectively opening and closing said main exhaust vent, a first duct which is separated from said main exhaust chamber and fluid-connected thereto and is positioned outside said main exhaust chamber, and a second duct which is fluid-connected with said first duct and positioned outside said first duct, said shift reaction unit being placed in said first duct, said CO oxidation unit being placed in said second duct.

20. The reforming apparatus according to claim 19, further comprising an exhaust sub-vent for discharging a burned exhaust gas within said first duct to the outside, and a shutter for selectively opening and closing said exhaust sub-vent.

21. The reforming apparatus according to claim 19, wherein at least one of said reforming reaction unit, said shift reaction unit and said CO oxidation unit is formed into a coil-like shape.

22. The reforming apparatus according to claim 19, further comprising an air feed channel for introducing fresh air into said second duct.

23. The reforming apparatus according to claim 1, wherein at least a portion of a raw material feed channel for feeding the raw material and steam to said raw material reforming unit is arranged in a position in which the raw material and the steam are preheated by heat from the heat source of said raw material reforming unit.

24. The reforming apparatus according to claim 23, wherein at least a portion of said raw material feed channel

is held in contact with the surface of at least one of said reforming reaction unit, said shift reaction unit and said CO oxidation unit.

25. The reforming apparatus according to claim 23, wherein at least a portion of said raw material feed channel is arranged at a position able to be contacted with the burned exhaust gas from the heat source of said raw material reforming unit.

26. The reforming apparatus according to claim 23, wherein at least a portion of said raw material feed channel is arranged at such a position that it can be directly heated by the heat source of said raw material reforming unit.

27. The reforming apparatus according to claim 1, wherein at least a portion of a fuel feed channel for feeding fuel to the heat source of said raw material reforming unit is arranged at a position able to be preheated by heat from the heat source of said raw material reforming unit.

28. The reforming apparatus according to claim 1, further comprising a combustion catalyst held in said heat source and a preheater for preheating the combustion catalyst, wherein the heat source of said raw material reforming unit generates heat by catalytic combustion.

29. A reforming apparatus comprising an integrated structure of four separate units, which comprises:

a combustion unit for generating heat by combustion of a fuel gas;

a raw material reforming reaction unit for steam-reforming a raw material and producing a reformed gas containing hydrogen as a principal component;

a shift reaction unit for decreasing CO contained in the reformed gas, that was produced in said raw material reforming unit, by water-gas-shift reaction;

a CO oxidation unit for further decreasing CO contained in the resultant reformed gas, that was treated in said shift reaction unit, by oxidation;

said reforming reaction unit and said shift reaction unit containing different catalysts, said shift reaction unit and said CO oxidation unit being indirectly heated by heat transfer from the heat source of said raw material reforming unit, said CO oxidation unit being positioned outside said reforming reaction unit, and said reforming reaction unit being directly heated by said combustion unit so that the temperature in said reforming reaction unit is controlled in the range of 400 to 1000° C., said shift reaction unit being indirectly heated by heat transfer from said combustion unit so that the temperature in said shift reaction unit is controlled in the range of 200 to 350° C., said CO oxidation unit being indirectly heated by heat transfer from said combustion unit so that the temperature in said CO oxidation unit is controlled in the range of 100 to 250° C.;

said CO oxidation unit including an outside surface, and being arranged to obtain atmospheric cooling of the outside surface; and

said raw material reforming unit, said shift reaction unit and said CO oxidation unit are concentrically arranged relative to each other with said CO oxidation unit placed on an outer peripheral side of the reforming apparatus.

30. A reforming apparatus comprising an integrated structure of three separate units, comprising:

a raw material reforming unit for steam-reforming a raw material to be reformed and producing a reformed gas containing hydrogen as a principal component, including a heat source that generates heat by combustion of a fuel gas, operable to directly obtain heat for the steam reformation reaction from said heat source;

a shift reaction unit for decreasing, by water-gas-shift reaction, CO contained in the reformed gas produced in said raw material reforming unit; and

a CO oxidation unit for further decreasing, by oxidation, CO contained in reformed gas treated in said shift reaction unit;

said raw material reforming unit and said shift reaction unit contain different catalysts, and said shift reaction unit and said CO oxidation unit being arranged in a manner that said shift reaction unit and said CO oxidation unit can be indirectly heated by heat transfer from the heat source of said raw material reforming unit, and further said CO oxidation unit including an outside surface, and being arranged to be cooled by atmospheric, raw material or water cooling of the outside surface; and

said raw material reforming unit, said shift reaction unit and said CO oxidization unit are concentrically arranged relative to each other with said CO oxidization unit placed on an outer peripheral side of the reforming apparatus.

31. The reforming apparatus according to claim 30, wherein said raw material reforming unit comprises a generally cylindrical combustion chamber as the heat source and a reforming reaction unit for steam-reforming the raw material to produce the reformed gas containing hydrogen as a principal component, said reforming reaction unit, said shift reaction unit and said CO oxidation unit are concentrically arranged relative to said combustion chamber.

32. The reforming apparatus according to claim 31, wherein said reforming reaction unit is concentrically accommodated within said combustion chamber.

33. The reforming apparatus according to claim 31, wherein said reforming reaction unit is positioned outside said combustion chamber in contact therewith.

34. The reforming apparatus according to claim 31, said combustion chamber comprising a center, and further comprising an incombustible core arranged at the center of said combustion chamber.

35. The reforming apparatus according to claim 31, wherein both of said shift reaction unit and said CO oxidation unit are positioned outside said reforming reaction unit.

36. The reforming apparatus according to claim 35, further comprising a partition wall having a function of regulating heat transfer, the partition wall being interposed between said reforming reaction unit and both of said shift reaction unit and said CO oxidation unit.

37. The reforming apparatus according to claim 35, wherein said reforming reaction unit and said shift reaction unit are connected by a flow path detouring outside both of said shift reaction unit and said CO oxidation unit.

38. The reforming apparatus according to claim 35, wherein said shift reaction unit is arranged on a side adjacent to a high temperature zone of said reforming unit and said CO oxidation unit is arranged on a side adjacent a low temperature said of said reforming reaction unit, so as to be in conformity to a temperature distribution within said reforming reaction unit.

39. The reforming apparatus according to claim 30, wherein each of said shift reaction unit and said CO oxidation unit is arranged in a position which is heated by a burned exhaust gas from said heat source of said raw material reforming unit.

40. The reforming apparatus according to claim 30, wherein said CO oxidation unit is arranged to be cooled by raw material cooling of the outside surface.

41. The reforming apparatus according to claim 30, wherein said CO oxidation unit is arranged to be cooled by water cooling of the outside surface.

42. A reforming apparatus comprising an integrated structure of four separate units, which comprises:

a combustion unit for generating heat by combustion of a fuel gas;

a raw material reforming reaction unit for steam-reforming a raw material and producing a reformed gas containing hydrogen as a principal component;

a shift reaction unit for decreasing CO contained in the reformed gas, that was produced in said raw material reforming unit, by water-gas-shift reaction;

a CO oxidation unit for further decreasing CO contained in the resultant reformed gas, that was treated in said shift reaction unit, by oxidation;

said reforming reaction unit and said shift reaction unit containing different catalysts, said shift reaction unit and said CO oxidation unit being indirectly heated by heat transfer from the

heat source of said raw material reforming unit, said CO oxidation unit being positioned outside said reforming reaction unit, and said reforming reaction unit being directly heated by said combustion unit so that the temperature in said reforming reaction unit is controlled in the range of 400 to 1000°C, said shift reaction unit being indirectly heated by heat transfer from said combustion unit so that the temperature in said shift reaction unit is controlled in the range of 200 to 350°C, said CO oxidation unit being indirectly heated by heat transfer from said combustion unit so that the temperature in said CO oxidation unit is controlled in the range of 100 to 250°C;

said CO oxidation unit including an outside surface, and being arranged to be cooled by atmospheric, raw material or water cooling of the outside surface; and

said raw material reforming unit, said shift reaction unit and said CO oxidization unit are concentrically arranged relative to each other with said CO oxidization unit placed on an outer peripheral side of the reforming apparatus.

43. The reforming apparatus according to claim 42, wherein said CO oxidation unit is arranged to be cooled by raw material cooling of the outside surface.

44. The reforming apparatus according to claim 42, wherein said CO oxidation unit is arranged to be cooled by water cooling of the outside surface.